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Short title The Technology and Craft Organisation of Kushite Technical Ceramic Production at Meroe and Hamadab, Sudan

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Abstract

This paper seeks to contribute to the growing knowledge of iron production in ancient Sudan by examining the technology and craft organisation involved in the production of technical ceramics, which were integral to the iron smelting process. The focus of this study are the technical ceramics including tuyères, furnace linings, and furnace bricks, recovered from various slag heaps located at the archaeological sites of the Royal City of Meroe and the Meroitic town site of Hamadab. We used macroscopic examination and thin-section petrography to identify the source of raw materials and methods used in preparing the raw materials, to characterise the level of craft specialisation, and to infer the broader socio-political developments that might have influenced how the production of technical ceramics was organised. The resulting data reveal that changes occurred within the production of technical ceramics throughout different periods of Kushite history (traditionally divided into Napatan and Meroitic) and during the post-Meroitic period, and we argue that the observed changes might have been related to the rise and fall of the Kingdom of Kush. The production of technical ceramics was marked by clear distinctions in raw materials and paste preparation methods used for different types of technical ceramics, and a high degree of compositional and technological homogeneity within each type of technical ceramic during the Napatan and earlier Meroitic periods, coinciding with the time when Kush rose to and was at the height of its power. The production of technical ceramics appears to have exhibited more diversity in terms of the raw materials and paste preparation methods and lower degree of homogeneity during the later and post-Meroitic periods when the economic and political influence and power of the Kingdom of Kush is described as declining and ultimately ceasing to exist. Perhaps the most drastic change in the production of technical ceramics took place in the post-Meroitic period, which was characterised by lower level of specialisation, as well as the possibility of using a different technological approach to iron smelting.

Keywords Technical ceramics; iron production; Sudan; African archaeology; macroscopic examination; thin-section petrography

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Highlights

- ☐ We examined the production of technical ceramics from Meroe and Hamadab, Sudan.
- ☐ Macroscopic examination and petrography were our principal analytical methods.
- ☐ Craft specialisation declined from the Kushite period to post-Meroitic period.
- ☐ Greater variety of raw materials and preparation methods are seen in later periods.

¶ We argue such decline may be linked to the development of the Kingdom of Kush.

1

1 **The technology and craft organisation of Kushite technical ceramic production at Meroe and**

2 **Hamadab, Sudan**

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38 **Abstract**

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40 examining the technology and craft organisation involved in the production of technical ceramics,

41 which were integral to the iron smelting process. The focus of this study are the technical ceramics

42 including tuyères, furnace linings, and furnace bricks, recovered from various slag heaps located at the

43 archaeological sites of the Royal City of Meroe and the Meroitic town site of Hamadab. We used

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59 which was characterised by lower level of specialisation, as well as the possibility of using a different
60 technological approach to iron smelting.

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71 **Keywords:** Technical ceramics; iron production; Sudan; African archaeology; macroscopic
72 examination; thin-section petrography

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75 **1. Introduction**

76 Iron production is argued to have been a crucially important technology for the Kingdom of Kush,
77 which lasted from at least the 8th century BC to the 4th century AD (Haaland, 2014: 658; Humphris,
78 2014; Humphris and Rehren, 2014; Shinnie, 1985; for a background to the Kingdom of Kush see
79 Török, 1997; Welsby, 1996). Kushite iron production is also argued to have had significant
implications

80 on the origin of iron metallurgy in sub-Saharan Africa (Childs and Killick, 1993; Killick, 2015: 310-
311;

81 Shinnie and Kense, 1982). However, our present understanding of the nature and scale of Kushite iron
82 production, based on the results of a few previous studies, is far from conclusive (Garstang et al.,
1911;

83 Rehren, 1995, 1996, 1997, 2001; Rehren et al., 1995; Shinnie, 1985; Shinnie and Kense, 1982;
Trigger,
84 1969; Tylecote, 1970, 1982). Against this background, UCL Qatar's archaeometallurgical research
was
85 initiated to fill important research gaps in current understandings of iron production during different
86 periods of Kushite history by using a multidisciplinary approach (Humphris, 2014; Humphris and
87 Carey, 2016; Humphris and Rehren, 2014; Charlton and Humphris, forthcoming; Humphris and
88 Scheibner, forthcoming). Working within this framework, the investigation presented here was
89 dedicated to the examination of the production of technical ceramics, which were integral to the iron
90 production processes. This study, therefore, serves to differ from previous Nubian ceramic analyses,
91 which largely centered on domestic pottery and/or fine-ware ceramics, by placing our emphasis on
92 technical ceramics (cf. Brand, 2016; Carrano et al., 2009a, 2009b; Daszkiewicz and Schneider, 2011;
93 Daszkiewicz et al., 2005; Dittrich, 2010; Edwards, 1999; Mason and Grzymiski, 2009; Smith, 1991,
94 1995, 1996, 1997, 1999). This study also serves to deviate from past technical ceramic
characterisation
95 works, which focused mostly on their refractory properties, by exploring the technology and craft
96 organisation involved in technical ceramic production. In order to address these aspects of production,
97 we focused on the technical ceramics recovered from slag heaps situated at two key Kushite
98 settlements: the Royal City of Meroe (Shinnie and Anderson, 2004) and the Meroitic town-site of
99 Hamadab (cf. Wolf and Nowotnick, 2013; Wolf, 2015). We used macroscopic examination and thin-
100 section petrography to examine the technical ceramics so as to characterise the sources of raw
materials
101 and methods used in preparing the raw materials. The resultant compositional and technological
102 variability enabled us to identify the technical practices and choices made by ancient producers, and
to
103 highlight the level of craft specialisation in relation to iron production. Ultimately, we aimed at
104 inferring to the socio-political developments of the Kingdom of Kush in which the production of
105 technical ceramics was organised.

106

107 **2. Background**

108 *2.1. Technical ceramics*

109 'Technical ceramics' here refer to ceramic materials that were used for ferrous-technical purposes as
110 opposed to domestic pottery and fine-ware ceramics (Chirikure and Rehren, 2004: 145; Martínón-
111 Torres and Rehren, 2014: 109-110; Veldhuijzen, 2005). We examined a wide range of technical
4

112 ceramics, including tuyères, furnace lining and furnace bricks, and furnace materials (Fig. 1).

Tuyères

113 are the blowpipes that were made of clay to supply and regulate airflow direction and quantity from
the

114 bellows to the furnace. Furnace linings are the additional layer of ceramic materials attached to the
115 interior surface of the furnace. Furnace bricks are the blocks or slabs of ceramic materials that were
116 used to build the furnace. Furnace materials refer to the ceramic materials that belong to be a part of
the

117 furnace structure and display varying degree of vitrification but cannot be firmly placed into the
118 category of furnace bricks or furnace linings.

119

120

121 Figure 1. Examples of technical ceramic remains (from left to right): tuyère fragments, furnace lining,

122 furnace brick, and furnace material.

123

124 *2.2. Archaeological Contexts*

125 The technical ceramic remains, together with fragments of slag, iron ore and charcoal, are among the
126 primary constituents of slag heaps, which are found in abundance within the landscape of certain
127 ancient Kushite settlements. The technical ceramics included in this study were recovered from
trenches

128 excavated in the following slag heaps: MIS (Meroe Iron Slag) 1/2, MIS2, MIS4, and MIS6 of the
Royal

129 City of Meroe, and slag heaps 100-200, 300 and 800 of Hamadab (Fig. 2). Calibration of
radiocarbon

130 dates of the slag heaps suggests that they were dated to various phases of the Kushite and post-
Meroitic

131 periods (Table 1; periodisation after Török, 2015). In this study, we use the traditional sub-division
of

132 Kush into two major periods, the earlier Napatan period from the beginning of the Kingdom until the
133 Meroitic period, which runs from ca. 280 BC to AD 350, although we recognise this division is
134 currently under critique; the term ‘Kushite period’ is used here to subsume both the Napatan and
135 Meroitic periods. Hence, an examination of technical ceramic remains recovered from these slag
heaps

136 allows us to trace the development of technical ceramic production during the Kushite period and
137 beyond.

5

138

139 Figure 2. Left: Sudan, with Khartoum marked as the blue star and Meroe and Hamadab (3km apart),
140 marked as the red star; Middle: The Royal City of Meroe with all slag heaps shown in red and the
ones

141 mentioned in this study labelled; Right: The slag heaps investigated at the Meroitic settlement of
142 Hamadab shown in red.

143

Site Location Calibrated dates Period

MIS4 ca. 8th – 2nd century BC Napatan to earlier Meroitic
periods

MIS2 ca. 5th – 2nd century BC Napatan to earlier Meroitic
periods

MIS1/2 ca. 4th – 1st century BC Napatan to earlier Meroitic
periods

Meroe

MIS6 ca. 2nd – 6th century AD Meroitic to post-Meroitic

300 ca. 3rd – 6th century AD Later Meroitic to post-Meroitic

Hamadab 100–200 ca. 4rd – 6th century AD Later Meroitic to post-Meroitic

800 ca. 4th – 6th century AD post-Meroitic

144 Table 1. The calibrated, modelled radiocarbon dates and equivalent archaeological periods of the
slag

145 heaps, where the technical ceramics were recovered and included in this study (after Humphris and
146 Scheibner, forthcoming).

147

148 2.3. Geological Setting

149 Most of the Sudan is underlain by Precambrian metamorphic and intrusive basement rocks, with large

150 areas being overlain by sedimentary cover rocks summarised as the so-called ‘Nubian Sandstone’
151 (Geological Map of the Sudan, 1981). The Nile, with its two main tributaries – the White Nile and Blue

152 Nile – merging at Khartoum, runs through the region. The Atbara River, with its headwaters in
153 Ethiopia, enters the main river system about 300km north of Khartoum. The three tributaries have
154 distinct mineralogical composition, thus contributing to the variation in the mineralogical composition

155 of the confluence area (Garzanti et al., 2006). The White Nile carries rounded monocrystalline quartz

156 with small amount of feldspar, the sediments of the Blue Nile contain mostly mafic volcanic grains, K-

157 feldspar, and biotite, and the Atbara River contributes volcanic rock fragments, augite, and olivine. The

6

158 Nile alluvium in the areas north of the confluence is described as more homogeneous, containing
159 mineral suites of quartz, feldspars, amphiboles, clinopyroxenes, mica, rounded fragments of basic
160 volcanic rock, and phytoliths of vegetation, which are mainly produced from weathering of the basaltic

161 Ethiopian Highlands (Mason and Grzymski, 2009). In spite of their apparent homogeneity in the
162 mineralogical composition, the grain size of the sediments is described to have decreased with distance

163 from the confluence area (Eisawi et al., 2015: 310).

164

165 The archaeological sites of the Royal City of Meroe and Hamadab are both located along the eastern cut

166 banks of the Nile: Meroe is situated ca. 150km north of Khartoum and Hamadab ca. 3km south of
167 Meroe. The geology of both sites is characterised by the presence of the Nile alluvium as described
168 above. In addition to the Nile alluvium, the areas to the north and east of the sites are underlain by
169 granitic gneisses, amphibolites, and hornblende gneisses, with outcrops of granites and basic volcanic

170 rocks. The areas to the south and west of the sites are underlain by sand- and mudstones of the Shendi

171 Formation, the local stratigraphic unit of the ‘Nubian Sandstone’ (Eisawi et al., 2015: 316-317).

172 Deposits of kaolinitic clays are interbedded with sandstone in the Shendi Formation (Eisawai et al.,
173 2015: 316-317; Robertson, 1992). The geomorphology of the region is also influenced by the seasonal

174 *wadi* drainage systems such as Wadi el-Hawad and Wadi Hadjala, which have the effect of transporting

175 and sorting sediments to the Nile (Wolf, 2015). We acknowledge that the above description of the
176 geology of the areas surrounding the sites is somewhat generalised, and that more detailed description

177 of the variation in the mineralogical composition specific to the sites will require the execution of
178 systematic geological surveying of the region, which is an ongoing effort of the project.

179

180 **3. Methods**

181 Macroscopic examination and thin-section petrography were used to examine the technical ceramics in

182 this study. Macroscopic examination was carried out to document traits such as shape, dimension and

183 fabric composition of the technical ceramic assemblages, and to select samples for further analysis.

184 Noteworthy is the inherent limitation in the archaeological sampling of tuyères, furnace linings, furnace

185 bricks and furnace materials owing to their fragmentary nature. A stratified sampling strategy was
186 applied to select tuyère samples to ensure the selected samples are representative of the variation that
187 exists within the assemblages, as well as the variation through time and across the sites. The tuyère
188 fragments were divided into macroscopic fabric groups based on variation in fabric colour, size and
189 relative abundance of inclusions. Within each macroscopic fabric group, the fragments were further
190 divided into subgroups according to their context of recovery, diagnostic features (i.e. nozzle end) and

191 shape. Diagnostic fragments were selected from each subgroup, and in case no diagnostic fragment was

192 present in the subgroup, non-diagnostic fragments were chosen instead. The application of the same
193 criteria on selecting furnace lining samples was challenged by the lack of variation observed in their
194 macroscopic fabric composition. Sampling of furnace brick and furnace material samples was equally

7

195 challenging because the macroscopic composition of furnace bricks and furnace materials appears to be

196 different from fragment to fragment, making it difficult to place the samples into macroscopic fabric
197 groups. Thus, the furnace lining, furnace brick, and furnace material samples were chosen according to

198 their contexts of recovery to ensure that the composition and technological characteristics of different

199 phases of Kushite and post-Meroitic periods were represented. In total, 70 tuyère, 25 furnace lining, 17

200 furnace brick, and 10 furnace material samples were selected for petrographic analysis (Table 2).

201

Site Location No. of tuyères No. of furnace lining No. of furnace bricks

No. of furnace materials

MIS4 6 9 2 n/a

MIS2 3 1 n/a n/a

Meroe MIS1/2 6 1 1 n/a

MIS6 21 14 14 n/a

100–200 26 n/a n/a 7

Hamadab 300 3 n/a n/a 2

800 5 n/a n/a 1

202 Table 2. The quantity of tuyère, furnace lining, furnace brick, and furnace material samples selected
203 from each slag heap at Meroe and Hamadab for petrographic analysis.

204

205 Since our focus is on the raw materials and methods used in making the technical ceramics rather than

206 their refractory properties, thin-section petrography is the ideal method, as it has been readily used to
207 examine the production of domestic pottery and/or fine-ware ceramics in the region; thus making our
208 data comparable with other ceramic studies (cf. Brand, 2016; Carrano et al., 2009b; Daszkiewicz and
209 Bobryk, 2003; Daszkiewicz and Schneider, 2011; Mason and Grzyski, 2009; Smith, 1991, 1996,
210 1997, 1999). Thin-section petrography characterises the composition of technical ceramic samples
by
211 identifying their mineralogical constituents. By comparing the mineralogical constituents with local
212 geological data, it has also made possible to establish the potential provenance of raw materials used
in
213 making technical ceramics. This analytical technique also sheds light on the technology used to
make
214 technical ceramics – especially paste preparation method and the level of standardisation involved –
by
215 characterising the relative and overall abundance, grain size, shape, and sorting of their inclusions
216 (Freestone, 1991; Quinn, 2013; Whitbread, 1995). We argue that the variation in mineralogical
217 composition and technological traits of the fabrics represents the presence of different ceramic
pastes,
218 each of which was unique to particular producers or production groups. The thin-section samples
were
219 prepared and analysed at the Laboratories of Archaeological Material Sciences at UCL Qatar.
220 Estimation of the relative abundance of inclusions was made with reference to the percentage chart
221 developed by Matthew et al. (1991).

222

223 **4. Results**

224 *4.1. Tuyères*

8

225 Macroscopically, where shape is identifiable, the majority of tuyères are cylindrical, but with
varying
226 external diameter, bore diameter, and wall thickness. Three variants – cylindrical shape, cylindrical
227 shape with thin wall, and cylindrical shape with thick wall – were identified (Fig. 3a). In addition to
the
228 cylindrical shape, some tuyères are square in shape with circular bore (Fig. 3b). It is interesting to
note
229 that correlations exist between the shapes of tuyères and their context of recovery. Cylindrical
tuyères
230 with thin wall occur in greater frequency in MIS1/2 and MIS2, whereas square-shaped tuyères are
231 associated with MIS4. Cylindrical tuyères with thick wall were only found in MIS6, although the
232 presence of tuyères of other shapes is also common in MIS6. The tuyères recovered from Hamadab
are
233 mostly cylindrical shaped, with a few square-shaped ones. The tuyères of same shape class
recovered
234 from each context are relatively homogenous in terms of their dimensions (Table 3).

235

236

237 Figure 3. Different shapes of tuyères identified: (a) (from left to right) cylindrical with thin wall,
238 cylindrical, and cylindrical with thick wall, and (b) square-shaped.

239

External diameter Bore diameter Wall thickness

Location Tuyère

shape max.

(cm)

min.

(cm)

mean

(cm)

s.d.

(cm)

r.s.d.

(%)

max.

(cm)

min.

(cm)

mean

(cm)

s.d.

(cm)

rsd

(%)

max.

(cm)

min.

(cm)

mean

(cm)

s.d.

(cm)

r.s.d.

(%)

MIS4 Square (n=4) 6.2 5.1 5.6 0.5 **9** 3.9 2.0 2.7 1.0 **39** 2.3 1.7 2.1 0.3 **14**

MIS2

Cylindrical

with thin

wall (n=3)

4.3 3.4 3.9 0.5 **12** 2.0 1.9 2.0 0.1 **3** 1.0 0.9 1.0 0.1 **6**

MIS1/2

Cylindrical

with thin

wall (n=3)

4.2 4.0 4.1 0.1 **2** 2.2 1.9 2.1 0.8 **1** 1.3 1.1 1.2 0.1 **10**

Cylindrical

(n=9) 6.1 4.2 5.4 0.7 **13** 3.8 2.2 3.2 0.7 **21** 2.0 1.4 1.8 2.0 **13**

Cylindrical

with thick

wall (n=4)

MIS6 6.4 6.1 6.2 0.1 **2** 3.6 2.4 3.2 0.7 **22** 3.5 2.0 2.8 0.3 **15**

Square (n=6) 6.2 5.5 5.9 0.3 **5** 3.8 2.2 3.3 0.6 **19** 2.2 1.6 1.9 0.2 **12**

Cylindrical

Hamadab* (n=21) 6.5 5.1 5.7 0.5 **8** 3.9 2.1 3.1 0.5 **17** 2.3 1.1 1.7 0.3 **19**

Square (n=4) 5.9 5.3 5.6 0.3 **5** 3.9 3.2 3.7 0.4 **11** 2.3 1.6 1.9 0.3 **17**

240 Table 3. The maximum value (max.), minimum value (min.), mean, standard deviation (s.d.), and

241 relative standard deviation (r.s.d.) of external diameter, bore diameter, and wall thickness of different

242 tuyère shapes by their context of recovery. Measurements were made on larger pieces of sample with

9

243 identifiable shape. *Note that the tuyères from Hamadab were measured altogether as the slag heaps

244 have similar calibrated radiocarbon dates.

245

246 On the microscopic level, the petrographic data reveal that the majority of samples (n=64) have
quartz
247 grains as the principal type of inclusion. These samples are further divided into four subgroups,
248 primarily based on the variation in paste preparation methods, even though the differences in
249 mineralogical composition and textural characteristics are also taken into consideration. Quartz
250 Subgroup A (n=32) stands out from other subgroups for its fine-grained fabric, consisting of 10 to
15%
251 of quartz and less than 3% of plagioclase feldspar, biotite, amphibole, and Fe-rich nodules in non-
252 calcareous clays (Fig. 4a). The inclusions are homogeneous in grain size, as well as in shape and
253 sorting. They measure between <0.05mm and 1.1mm with a mode size of 0.1mm. The mineralogical
254 constituents of these samples are consistent with the Nile alluvium, pointing to the use of local raw
255 materials in making the tuyères of Subgroup A. Impression of plant fiber (<1%) is identified, but
only
256 in a few samples (Fig. 4b). Whereas the plant fiber could have occurred naturally in the Nile clay, it
is
257 also possible that plant materials might have been added to the clay as temper, as is evidenced by the
258 presence of elongated pores, accounting for approximately 3% of the matrix. The use of organic
259 materials, which would have burnt out and left voids during use, is argued to have the effect of
260 increasing technical ceramics' resistance to potential fractures due to sudden temperature changes
261 (Martín-Torres and Rehren, 2014: 123). This refractory property is of particular importance in
262 making tuyères because they would have been exposed to higher temperatures when projected into
the
263 furnace close to the combustion zone (Freestone, 1989: 156).
264
265
266

10

267 Figure 4. Photomicrographs showing the fabric of (a) Quartz Subgroup A, (b) impression of plant
fiber
268 of a sample from Subgroup A (indicated by arrow), (c) Quartz Subgroup B, (d) Quartz Subgroup C,
(e)
269 Quartz Subgroup D, and (f) the Kaolinite-tempered Group (kaolinite fragments indicated by arrows).
270 All photomicrographs were taken in XP at x50 magnification.

271

272 The remaining subgroups all exhibit evidence of clay mixing, but each with a different method
applied.

273 Quartz Subgroup B (n=13) is marked by the addition of clay pellets to clays (Fig. 4c). The clay
pellets

274 have fine-grained quartz inclusions and clear boundaries, which occur in a wide range of sizes
(0.1mm

275 to 4.5mm and no clear mode size), relative abundance (5% to 10%) and sorting. The clay pellets
were

276 added to non-calcareous clay, consisting of approximately 5% of fine-grained quartz and less than
3%

277 of fine-grained plagioclase feldspar, biotite, amphibole, and Fe-rich nodules. Quartz Subgroup C
 (n=10)
 278 is distinguishable by the presence two or more clays, which were mixed when they were wet, as seen
 in
 279 the lack of clear boundary between the interface of clays (Fig. 4d). The clays are non-calcareous,
 280 including an orange-brown clay with 5% of fine-grained quartz and less than 3% of fine-grained
 281 plagioclase feldspar, biotite and amphibole, a greyish-brown clay with 10% to 15% of fine-grained
 282 quartz, and a brown clay with 5% to 10% of fine-grained quartz and 5% of fine-grained Fe-rich
 283 nodules. Quartz Subgroup D (n=9) is characterised by both mixing wet clays and adding clay pellets
 284 (Fig. 4e). In these samples, brown clay with 5% to 10% of fine-grained quartz and less than 3% of
 285 plagioclase feldspar, biotite, and amphibole was mixed with greyish brown clay, with little to no
 286 inclusions of quartz. Quartz grain-rich clay pellets of a variety of size (0.1mm to 3.5mm and no clear
 287 mode size), relative abundance (5% to 10%) and sorting were added to the clays. Overall, these
 288 subgroups display a great degree of internal heterogeneity, as a result of mixing varying types and
 289 proportions of clay pellets and clays. Again, the identification of quartz, plagioclase feldspar, biotite
 290 and amphibole in some clays point to the use of Nile alluvium for at least some of the raw materials
 291 used to make the tuyères of these subgroups. The identification of clay mixing in these samples has
 292 significant implications because such paste preparation method had been commonly used in making
 293 domestic pottery and fine wares during the Meroitic period (Brand, 2016: 82; Mason and Grzymiski,
 294 2009; Smith, 1997). Thus, it highlights the potential that the same producers were responsible for
 295 making technical ceramics, domestic pottery and fine wares, or the existence of cross-craft
 296 technological interaction between the producers of technical ceramics and those of domestic pottery
 and
 297 fine wares.
 298
 299 The petrographic data also reveal that there are a few samples (n=6) that can be placed in the
 Kaolinite-
 300 tempered Group. These samples are characterised by the presence of kaolinite fragments as the
 301 principal type of inclusion (Fig. 4f). The addition of kaolinite is said to have the effect of increasing
 the
 302 refractory properties of technical ceramics, with its use being reported in making tuyères at several
 pre-
 303 colonial and colonial Eastern African sites (Martín-Torres and Rehren 2014, 121; Humphris,
 2004).
 11
 304 The kaolinite fragments of the samples are angular, and measure between 0.2mm and 3.5mm with a
 305 mode size of 1.0mm. Approximately 10% to 15% of kaolinite fragments were added to non-
 calcareous
 306 clays consisting of 5% to 15% of fine-grained quartz and less than 3% of fine-grained plagioclase
 307 feldspar, biotite, amphibole, and Fe-rich nodules. The presence of kaolinite was reported in various
 308 places in Sudan, including the First and Second Cataracts in Lower Nubia (Smith 1997), Meroe in
 309 Upper Nubia (Robertson 1975), Umm Ali (Smith 1997), and Musawarat es-Sufra (Smith 1999). The
 310 reconnaissance of raw materials in the catchment area of the sites conducted as part of the UCL
 Qatar
 311 research had located several deposits of kaolinite (Fig. 5). Whether or not these deposits of kaolinite
 312 were used in making the tuyères requires further analysis on their chemical composition, but this

313 finding, coupled with similarity of the mineralogical constituents of these samples to the Nile
alluvium,
314 again suggests the potential use of raw materials procured from the vicinity of the sites in making the
315 kaolinite-tempered tuyères.
316
317
318 Figure 5. Kaolinite deposit in the area adjacent to the archaeological site of Royal City of Meroe.
319
320 By comparing the variations observed at macroscopic and microscopic levels, no correlation
between
321 the tuyère shapes and fabric groups is observed (Table 4). The same fabric, Quartz Subgroup A, was
322 used to make tuyères of all shapes recovered from all trenches and sites. Three different fabrics,
namely
323 Quartz Subgroups A and C, and Kaolinite-tempered, were used to make the cylindrical tuyères with
324 thick wall characteristic of MIS6. All fabrics were used to make the cylindrical tuyères from
Hamadab.
325 Conversely, it seems strong correlations exist between the contexts of recovery and fabric groups
and
326 their associated paste preparation techniques (Table 4). The production of tuyères recovered from
327 MIS1/2, MIS2 and MIS4 involved no clay mixing, their samples being only associated with the
fabric
328 of Quartz Subgroup A. The production of tuyères of MIS6 and Hamadab was marked by mixing clay
329 pellets and wet clays, and adding kaolinite temper, as reflected in the identification of fabrics of
Quartz
330 Subgroups B and C and Kaolinite-tempered Group among their samples. The practice of mixing clay
12
331 pellets and wet clays in the same ceramic paste as seen in the fabric of Quartz Subgroup D appears
to be
332 solely related to making the tuyères recovered from Hamadab.

333

Location Tuyère shape Quartz

Subgroup A

Quartz

Subgroup B

Quartz

Subgroup C

Quartz

Subgroup D

Kaolinitetempered

MIS4 Square 4 Unidentified 2

MIS2 Cylindrical

with thin wall 3

Cylindrical

MIS1/2 with thin wall 3

Unidentified 3

Cylindrical 1 6 1 1

Cylindrical

with thick wall 2 1 1

Square 1 2 1 2

MIS6

Unidentified 1 1

Cylindrical 8 2 5 5 1

Hamadab Square 2 1 1

334 Table 4. The distribution frequency of fabric groups in relation to tuyère shape and context of
335 recovery.

336

336 4.2. Furnace linings

337 The furnace lining fragments recovered from MIS1/2, MIS2, MIS4, and MIS6 share similar
338 macroscopic features, characterised by dark fabric colour and abundant amount of white inclusions.
339 These fragments also share similar mineralogical composition and texture, as highlighted by the
340 petrographic data. Quartz grains are the principal and only type of inclusion, which are distinctively
341 well-rounded in shape and display a strong mode of 0.8mm in grain size (Fig. 5a and b). Their
342 abundance is consistent across all samples, accounting for approximately 30% of the fabric. The
343 quartz

343 grains are found in a matrix that is highly vitrified and displays microscopic structures reminiscent
344 of

344 slag. A possible explanation to this observation is that the clay component of the furnace linings
345 melted

345 and mixed with slag during smelting. This hypothesis is supported by the identification of fractures
346 within the quartz grains, as well as the presence of fractures between the interface of quartz grains
347 and

347 their surrounding matrix; suggesting that the samples were subjected to high firing temperatures.
348 Based

348 on this finding, we raise the speculation that the furnace linings could have been made deliberately
349 to

349 melt and facilitate the smelting process (Craddock et al., 2007; Crew, 2000; David et al., 1989;
350 Veldhuijzen, 2005; Veldhuijzen and Rehren, 2007: 195), although the verification of this hypothesis
351 warrants further analysis of the chemical composition of slag. Current understanding of the iron
352 smelting technology suggests rather that this lining was added to protect the furnace structures,
353 which

353 were reused numerous times. When destroyed, the lining could be removed and discarded on the
354 slag

354 mounds with the other metallurgical debris, and a new lining applied. The high degree of
355 vitrification of

355 the clay component of the samples has made it difficult to determine the sources of clay used in
356 making

356 the furnace linings. That being said, the roundness and homogeneous grain size of quartz inclusions
357 point to nearby *wadis* as their potential source, as the seasonal stream systems had the effect of
358 sorting

13

358 and depositing quartz sands. Alternatively, the high degree of homogeneity in the grain size of
359 quartz

359 inclusions might have been attained through sieving or winnowing and adding the quartz as temper
360 in a

360 standardised way. In either case, it appears that the producers were very specific in their selection of
361 quartz temper in making furnace linings to enhance their refractory properties (Kilikoglou et al.,
362 1998;

362 Tite et al., 2001).

363

364

365

366 Figure 5. Photomicrographs showing the fabric of (a) furnace lining from MIS2, (b) furnace lining
from

367 MIS6 with fractures within quartz grain, (c) furnace brick from MIS4, (d) furnace brick from MIS6

368 (slag inclusions indicated by arrows), and (e) furnace materials from Hamadab. All

photomicrographs

369 were taken in XP at x50 magnification.

370

371 4.3. *Furnace bricks*

372 Macroscopically, the furnace bricks recovered from MIS1/2, MIS2, MIS4, and MIS6 are identifiable
373 for their pale yellowish brown and/or reddish brown fabric colour and crumbly texture, implying that
374 they were probably unfired. The furnace bricks are also characterised by the presence of different
types

375 of inclusions of varying grain sizes and abundance. The petrographic data confirm the compositional
376 and textural variability, which is attributable to mixing different types and proportions of clays; thus
377 making the division of samples into groups difficult. Whereas quartz grains are the principal type of
378 inclusion in all furnace brick samples, just as other types of technical ceramics in this study, the
quartz

379 grains of furnace brick samples are coarser-grained (0.2mm and 4.5mm with no clear mode size) and
380 more angular than those of the tuyères and furnace linings (Fig. 5c). In some furnace brick samples,
the

381 quartz grains are found together with fine-grained plagioclase feldspar, biotite, amphibole, and Fe-
rich

382 nodules. Slag fragments, which measure between 0.4mm and 2.3mm, are also identified in the
samples

14

383 that are exclusively associated with MIS6, even though their occurrence is only very rare (<1%) in
each

384 sample (Fig. 5d). The identification of the rare occurrence of slag fragments indicates that they were
385 likely incorporated accidentally rather than added intentionally to the paste for furnace bricks. We,
386 therefore, suggest that the furnace bricks recovered from MIS6 might have been produced at or in
close

387 proximity of the site where smelting took place. We further argue that the producers might have used
388 whatever clays and raw materials that were available to make the paste for furnace bricks, including
the

389 use of the Nile clays that were also intended for tuyère production. This hypothesis would support
the

390 low degree of standardisation involved in preparing the pastes for furnace bricks, as reflected in the
391 high degree of heterogeneity in the grain size, abundance and sorting of inclusions in these samples.

392

393 4.4. *Furnace materials*

394 Furnace materials, i.e. material displaying a gradual degree of vitrification across the sample, were

395 recovered exclusively from Hamadab. Macroscopic examination of the furnace materials show that
they
396 are similar to the furnace bricks in terms of their pale yellowish brown fabric colour and the
presence of
397 different types of inclusions of varying grain sizes and abundance. However, the furnace materials
do
398 not have a crumbly texture like the furnace bricks, suggesting that they might have been subjected to
399 firing. This observation is supported by the petrographic data, which show that the furnace materials
are
400 characterised by the presence of quartz grains with fractures in a non-calcareous clay matrix that is
401 partially vitrified and displays structure similar to slag, just as the furnace linings. However, the
quartz
402 grains in the furnace materials lack the high degree of homogeneity in grain size, shape, and sorting
as
403 seen in the furnace linings. The quartz grains are angular in shape and display a wide range of sizes,
404 measuring between 0.2mm and 5.0mm with no clear mode size (Fig. 5e). The heterogeneity of
quartz
405 inclusions suggests that they were likely procured from sources different from those used in making
406 furnace linings of previous periods as described above, or reflects a low degree of standardisation in
407 preparing the materials with little effort to remove the coarse particles and/or refine the clays. The
408 determination of the potential provenance of the clays used in making furnace materials is difficult
409 owing to the high degree of vitrification of the matrix, as well as the lack of mineralogical
constituents
410 in the remaining clay component that are indicative of their geological origins.

411

412 **5. Discussion**

413 Our analyses reveal that the production of technical ceramics during the entire Kushite and post-
414 Meroitic periods shared a common feature, that is the use of local raw materials, particularly the Nile
415 clays. This finding corresponds with the results of other studies, which demonstrate that Nile clays
were
416 procured to manufacture domestic pottery and fine wares in the region (cf. Bourriau et al., 2000;
Brand,
417 2016; Carrano et al., 2009b; Daszkiewicz and Bobryk, 2003; Daszkiewicz and Schneider, 2011;
Mason
418 and Grzymski, 2009; Smith, 1991, 1996, 1997, 1999). Whether or not the same clay sources were
used
419 in making the domestic pottery and fine-ware ceramics that were found together with the technical
15
420 ceramics in the slag heaps requires further analyses. Nevertheless, the identification of the use of the
421 Nile clays in making the technical ceramics has emphasised the ability of the producers to acquire
local
422 raw materials and work within the constraints of those available in order to maximise their useful
423 properties (Craddock et al., 2007: 8; Freestone and Tite, 1986: 60-61). In addition to this
observation,
424 we have highlighted several major trends in the technology and craft organisation involved in
making
425 technical ceramics during the Kushite and post-Meroitic periods at Meroe and Hamadab.

426

427 *5.1. Napatan and earlier Meroitic periods at Meroe*

428 The production of tuyères, furnace linings and furnace bricks was marked by high level of
429 specialisation during the Napatan and earlier Meroitic periods, as represented by the samples from
430 MIS4, MIS2 and MIS1/2. Owing to the absence of direct evidence of production such as ceramic
431 workshops at Meroe and Hamadab to date, we define specialisation by using indirect evidence
(Costin
432 1991, 31-40), particularly the skills and technological know-how of producers, and the degree of
433 standardisation in ceramic fabrics and end products. It is clear that the producers had the knowledge
of
434 using specific raw materials and paste preparation methods to make particular types of technical
435 ceramics. As the results of the petrographic analysis confirm, there is no overlap in the fabrics for
436 tuyères, furnace linings and furnace bricks. The fabrics used for making tuyères and furnace linings
437 exhibit a high degree of standardisation, which is reflected in the high degree of homogeneity in
grain
438 size, abundance, shape, and sorting of inclusions. The degree of standardisation of the fabrics used
for
439 furnace bricks is not as high as the other two types of technical ceramics. We interpret such variation
in
440 standardisation of fabrics as further evidence demonstrating the skills and technological know-how
of
441 producers. It appears that the producers were aware of the fact that tuyères and furnace linings
should
442 have higher thermal shock resistance as opposed to furnace bricks because the collapse of tuyères
and
443 furnace linings might inhibit the process of iron smelting (Martínón-Torres and Rehren, 2014: 114).
444 Thus, the raw materials used to make the pastes for tuyères and furnace linings were procured from
445 specific sources and prepared in standardised ways to enhance their thermal stability. As for the
tuyères,
446 the same fabric, i.e. Quartz Subgroup A, was used to make the square-shaped examples from MIS4
and
447 the cylindrical ones with thin wall from MIS2 and MIS1/2. This finding suggests that even though
there
448 was different preference for tuyère shapes during the Napatan and earlier Meroitic periods, and
despite
449 the fact that these slag heaps probably represent the waste of different smelting workshops and cover
a
450 relatively long time span, the producers shared the same knowledge in paste preparation,
highlighting
451 continuity in tuyères production through time. We have little evidence to explain why different
tuyère
452 shapes were preferred at different phases of the Meroitic period. It is premature at this stage to argue
453 that different smelting methods were used on the basis of the variation in tuyère shape and associated
454 bore diameter, as we are unable to estimate whether there was a change in the volume of airflow
being
455 channeled into the furnace without the recovery of tuyères in their full length. Nonetheless, the end
456 products of each tuyère shape are highly standardised as shown in the low relative standard deviation

value of their respective measurements of external diameter, bore diameter, and wall thickness (Table 3).

459

5.2. *Later Meroitic and post-Meroitic periods at Meroe*

Just as the case of the technical ceramics of Napatan and earlier Meroitic periods, the production of technical ceramics during the later and post-Meroitic periods at Meroe continues to exhibit high level of

technological know-how of the producers. This is highlighted by the analysis of the samples from MIS6, showing that there is no overlap in the ceramic fabrics used to make tuyères, furnace linings, and

furnace bricks. The production of furnace linings and furnace bricks during the later periods, in particular, displays further similarity to their earlier counterparts in the level of standardisation of fabrics. The fabrics for furnace linings are highly standardised, as reflected in their quartz inclusions that are homogeneous in abundance, shape, size, and sorting, whereas the ceramic fabrics for furnace bricks have low level of standardisation. However, the production of tuyères during the later periods appears to have deviated from their earlier counterparts in terms of the level of standardisation of fabrics and end products. The identification of the presence of four fabrics – Quartz Subgroups A, C and D, and Kaolinite-tempered – among the tuyère samples suggests that greater variety of raw materials (i.e. clays of different sources and kaolinite) and paste preparation methods (i.e. clay mixing)

were used. With the exception of the samples of Quartz Subgroup A, all samples exhibit heterogeneity

in the proportions of clays being mixed, as well as the abundance, size, and sorting of inclusions.

Furthermore, a greater variety of tuyère shapes, including cylindrical, cylindrical with thick wall, and

square, is identified. Yet in spite of the variation in shape, the bore diameter is consistent across all tuyère shapes, with an average that measures ca. 3.2/ 3.3cm, whereas the outer diameter and wall thickness only vary slightly among tuyère shapes (Table 3). This finding, coupled with the lack of correlation between tuyère shapes and fabrics, has led to two hypotheses. The first hypothesis is that the

tuyères discarded at MIS6 were supposed to be similar in shape, but the lack of standardisation in the execution of technical practices might have contributed to the observed difference in tuyère shapes, resulting in some cylindrical tuyères being slightly larger than the others. As for the square-shaped tuyères, they might have been caused by stacking the unfired cylindrical tuyères during drying, as shown by experimental work. The second hypothesis is that different tuyère shapes were used at different phases within the later periods at Meroe, but verification of this hypothesis requires more refined stratigraphic excavation and data analysis. MIS6 spans over a timeframe of roughly 300+ years

(Humphris and Scheibner, forthcoming), incorporating the chronological shift from Meroitic to post-Meroitic. It is perhaps therefore unsurprising that a degree of heterogeneity in certain aspects of technical ceramic production is evident, as the social, economic and political environment within which

the iron production took place was changing. Overall, by comparing the production of tuyères, furnace

492 linings and furnace bricks, we postulated that the producers still possessed high level of
493 technological
494 know-how, but the level of skill and standardisation involved in executing the production of
495 technical
496 ceramics, especially tuyères, decreased during the later Meroitic and post-Meroitic periods.
497 5.3. *Later Meroitic and post-Meroitic periods at Hamadab*
498 The production of technical ceramics during the later Meroitic and post-Meroitic periods at
499 Hamadab
500 appears to differ from the previous periods at the Royal City of Meroe in at least two main ways.
501 Firstly, the distinction in the ceramic fabrics for different types of technical ceramics is not as clear.
502 Whereas the fabrics used for making tuyères are still separated from those for other technical
503 ceramics,
504 it is difficult to differentiate the fabrics for furnace linings and furnace bricks. Such lack of
505 distinction
506 of fabrics for furnace linings and furnace bricks, as we suggest here, might have implied that furnace
507 linings were used per se and that the furnaces were not designed to be reused at Hamadab as was the
508 case of the previous periods at Meroe. This argument is supported by the type and abundance of
509 metallurgical remains found in the slag heaps at Hamadab, where we see less tapped slag and more
510 furnace material discarded when compared to Meroe, implying a smelting technology less associated
511 with re-useable furnaces. Thus, it is likely that the concept of lining the furnace for reuse that was
512 seen
513 at the Meroe sites was not used as a technological approach at Hamadab, and rather that furnaces
514 were
515 dismantled more frequently at Hamadab. Secondly, the petrographic analysis shows that even greater
516 variety of raw materials were used in making the fabrics for tuyères and furnace materials, and that
517 the
518 fabrics were generally marked by a lower level of standardisation as evident in the great degree of
519 heterogeneity of the abundance, size, shape, and sorting of the inclusions. As for the tuyères, in
520 particular, the end products of cylindrical and square-shaped tuyères are standardised as expressed in
521 the low standard deviation values of their respective external diameter, bore diameter, and wall
522 thickness; but the same fabrics were used to make both types of tuyères. The discrepancy in the level
523 of
524 standardisation between the fabrics and end products of the tuyère samples highlights the possibility
525 that the producers at Hamadab seem to have had similar concepts of what tuyères should look like,
526 but
527 with greater liberty in executing the manufacturing process, especially the selection of raw materials
528 and paste preparation method. Overall, we suggest that the observed variation in the production of
529 technical ceramics at Hamadab and Meroe might be attributed to the changing social, economic and
530 political framework of the Kingdom of Kush, in which the producers at Hamadab, who although
531 operating for a time contemporaneously to the producers at Meroe represented by the earlier levels
532 of
533 MIS6, were not producers at a capital site. Therefore, central control over production might have
534 existed at Meroe (especially in the earlier periods) but never at Hamadab, and while the technology
535 or
536 iron production at Meroe had over a one thousand year history embedded within its practice, the

526 production at Hamadab began only in the final years of the Meroitic period, perhaps these being the
527 only years another site so close to Meroe was allowed to potentially compete for market demand for
528 iron. Alternatively, the Hamadab iron production may have been a reaction to the apparent decrease
in

529 scale of iron production at Meroe during the later times (Humphris and Scheibner, forthcoming;
Carey

530 et al., forthcoming), creating a situation whereby Hamadab was forced to cater for its own demand,
18

531 without the degree of knowledge or specialisation that marked but gradually declined in the remains
532 evident at MIS6.

533

534 **6. Conclusion**

535 We argue that the observed changes in the production of technical ceramics were linked to the
broader

536 socio-political developments of the Kingdom of Kush. The higher level of specialisation
characteristic

537 of the production of technical ceramics during the Napatan and earlier Meroitic periods at Meroe
538 coincided with the period when the Kingdom of Kush was at its height of power. It has been
suggested

539 that iron production might have been controlled by royal elites, as reflected in the close proximity of
540 slag heaps to Royal residence at Meroe (Haaland, 2014; Shinnie, 1985). If this was the case, it was
541 likely that the manufacture of technical ceramics during this period was also organised by elites
directly

542 or indirectly as part of their control of iron production, resulting in the evident standardised practices
543 regarding the selection of raw materials and paste preparation methods for tuyères, furnace lining,
and

544 furnace bricks. Yet, the level of standardisation involved in the production of technical ceramics
545 appears to have decreased during the later Meroitic period and post-Meroitic at Meroe when the
power

546 of the Kingdom of Kush is said to have been in decline. During this time, the elites may have had
less

547 control over iron production, including the manufacture of technical ceramics. Subsequently, the
548 producers appear to have greater liberty in the execution of production, even though these producers
549 might have been bounded by similar technological knowledge as those of previous periods. Perhaps
the

550 most drastic change in the production of technical ceramics occurred during the post-Meroitic period
551 and is evident in the comparison between Meroe, which technical knowledge was presumably
retained,

552 and Hamadab, which appears to have only then begun its own iron production. During this period, it
553 seems that more individuals might have attempted to produce technical ceramics, but improvising
with

554 their own technological knowledge and practices; thus contributing to the low level of
standardisation

555 that characterised the later Meroitic and post-Meroitic production of technical ceramics at Hamadab.
556

557 This study has served to contribute to illuminating the link between iron production and the rise and
fall

558 of the Kingdom of Kush, even though cross-referencing with other lines of evidence such as slag and
559 iron ores are necessary to solidify such link. In addition, this study has demonstrated the value of
using
560 macroscopic examination and petrographic analysis to address different aspects of technical ceramic
561 production, with particular emphasis on their manufacturing technology and craft specialisation
rather
562 than their refractory properties. An important step in the future of this work will be to compare our
563 results with the production of domestic pottery and fine-ware ceramics so as to delineate the inter-
craft
564 technological interaction and how the ceramic economy was organised; thus bringing about a more
565 wholesale understanding of different facets of Kushite society.

566

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19

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578

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